Molten salt-loop development acceleration with distributed single-crystal harsh-environment optical fiber-sensors

Michael Buric, NETL: presenter
With Pattrick Calderoni (INL), Ruchi Gahkar (INL), and Koroush Shirvan (MIT) (co-PI's)

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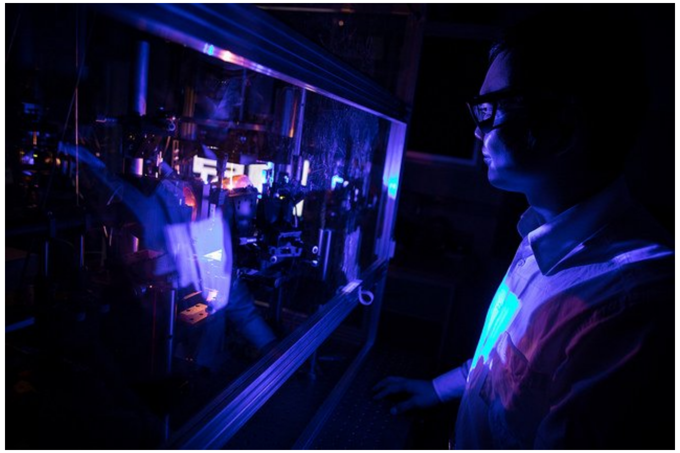
Single Crystal Distributed Sensing: Project Objectives

- Introducing fully-distributed sensing to Molten-Salt Reactors
- Growing new cladded single-crystal optical fibers for molten-salt environments
- Gathering thousands of data-points to map reactor coolant-path temperatures or other parameters
- Mapping in-core temperature distributions
- Next-gen sensing replaces single-point sensors like thermocouples
- Providing data to guide reactor design and improvement through thermal efficiency
- How?: Novel 2-stage LHPG, Raman distributed interrogation

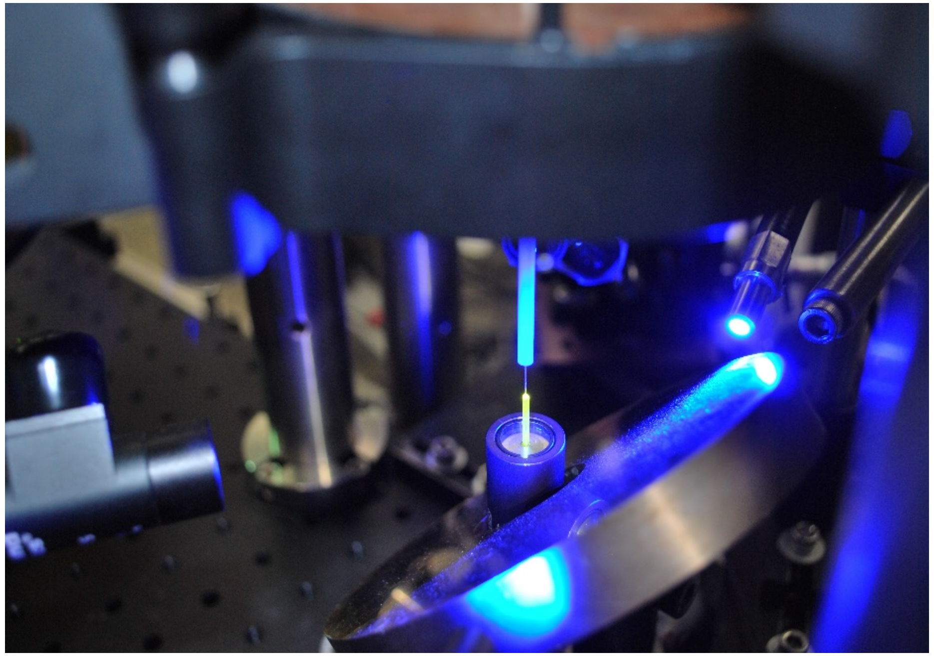


Single Crystal Distributed Sensing: Team

- National Energy Technology Lab (fiber growth, sensor design, interrogator design)
  – Michael Buric (PI, fiber optics and systems)
  – Guensik Lim (LHPG)
  – Juddha Thapa (Optical systems)
- Idaho National Lab (reactor expertise, system implementation and testing)
  – Pattrick Calderoni
    (in-pile instrumentation director, co-PI)
  – Joshua Daw (nuclear instrumentation)
  – Ruchi Gakkar (nuclear materials)
- MIT (material compatibility, efficacy simulations)
  – David Carpenter (Irradiation Engineering Director)
  – Koroush Shirvan (reactor design and simulation, co-PI)
- Note: I love this team!

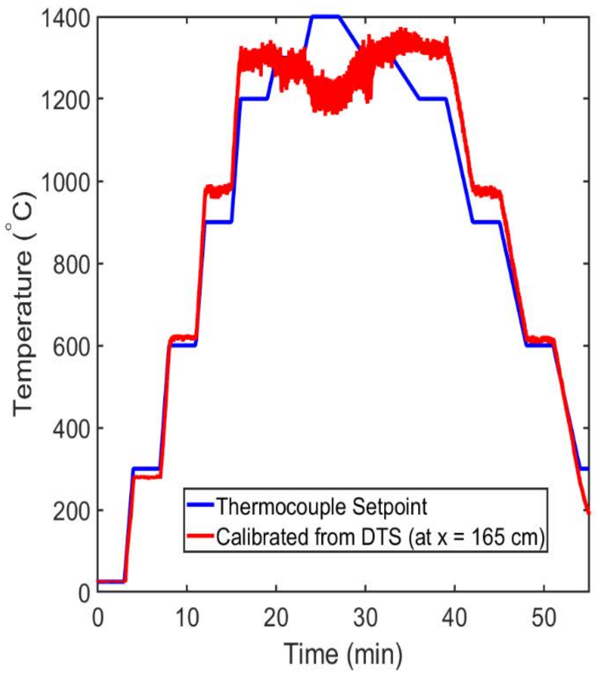
Single Crystal Distributed Sensing: Project Accomplishments

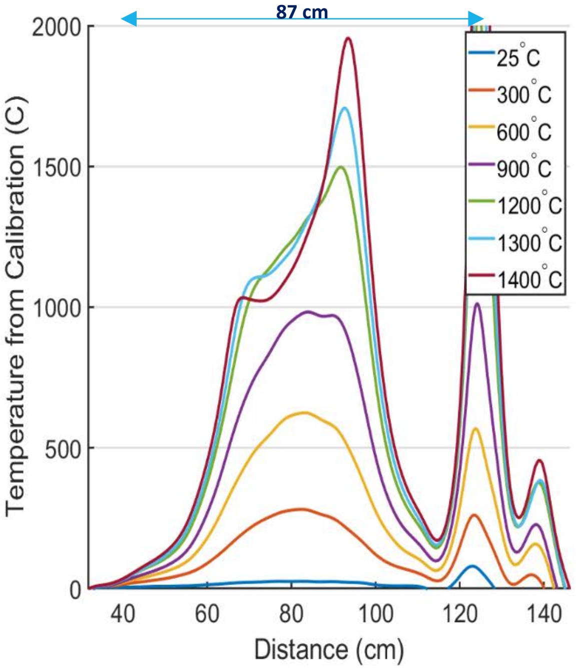
- Successful completion of materials compatibility studies
- Construction of Molten salt test setup
- Completion of Reactor Simulation
- Successful growth of pure feedstock materials
- Progress on second LHPG operation

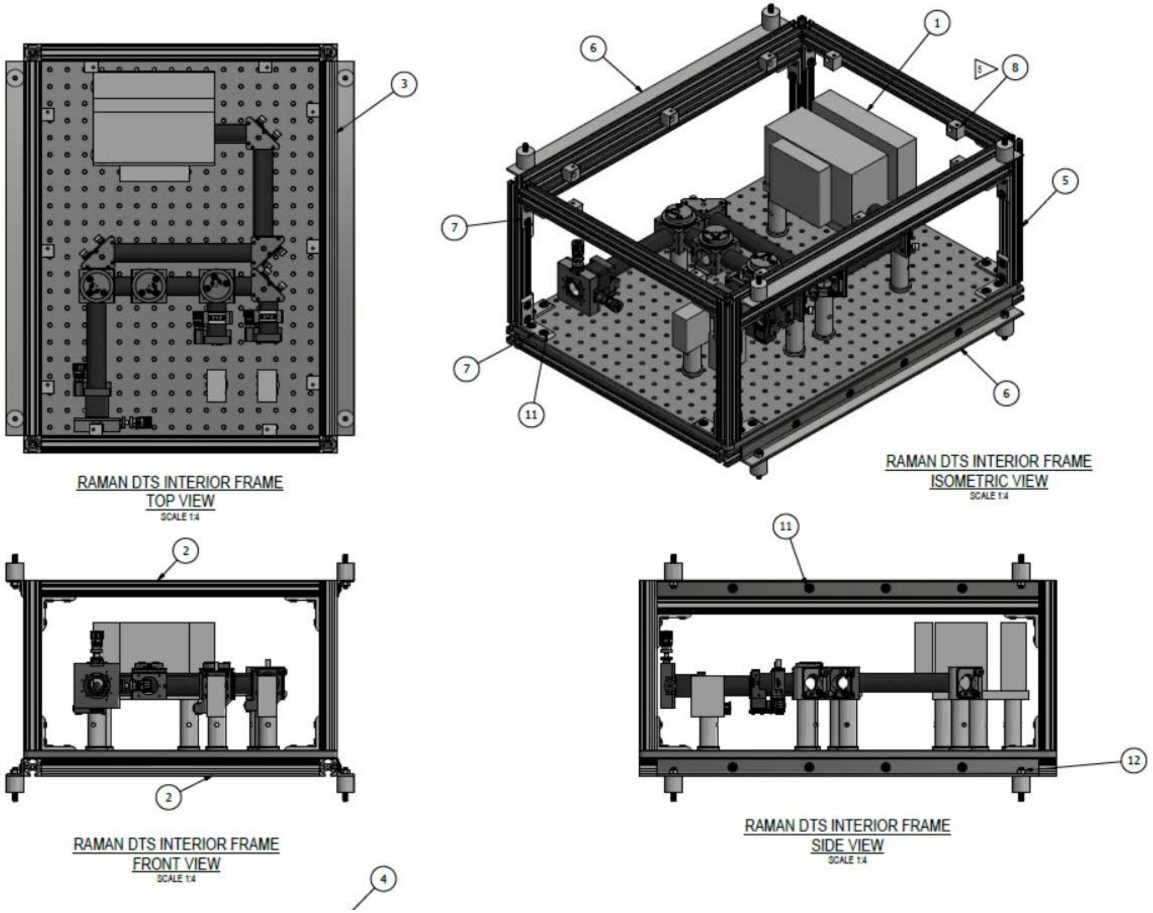


First successful growth of Cerium YAG fiber by LHPG

Project accomplishments: LHPG and Raman DTS







- First DTS with YAG
- First Ce-doped YAG fiber
- Raman DTS product design complete, ready for field tests in July

Project accomplishments – materials compatibility

Recommendations for fiber protection materials

Protective coating Type	Chloride Salts	Fluoride Salts
Metallized fibers	Ni, Mo and Ta	Ni, Mo and Ta
Tubular fiber sleeves (primary choice)	SS316	Ni-200
Tubular fiber sleeves (further considerations)	Alloy 617, 800H and TZM (Titanium Zirconium Molybdenum (98-99% Mo)	Hastelloy and Haynes alloys

Project accomplishments – molten salt testing

Experimental Setup at INL

SS316 Capillary

Thermocouple

Alumina lid

Fiber: Heat-treated Pure Silica core, f-doped cladding single mode optical fiber

Salt-mixture: NaCl-$MgCl_2$ eutectic

Crucible: Glassy carbon, dimensions H: 80mm, D: 37mm

Data recorded: 466, 500, 525, 550, 575, 600, 625 and 650°C

Depth of thermocouple inserted in salt – below the set screw

With respect to the fiber:

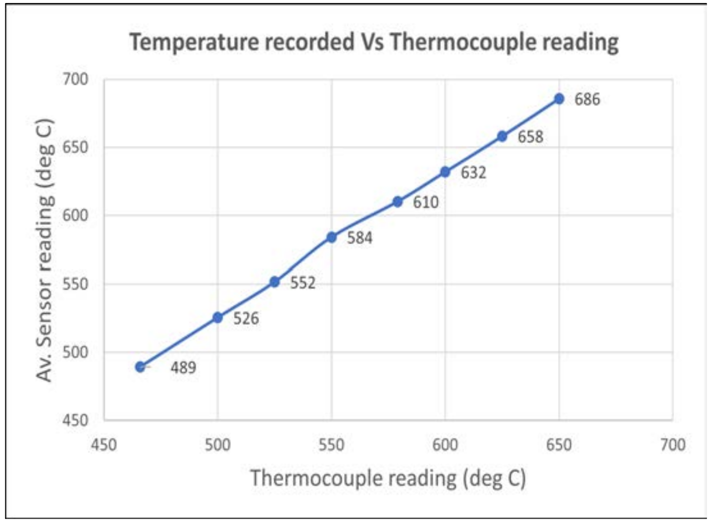
Top of Lid: 358.8 cm

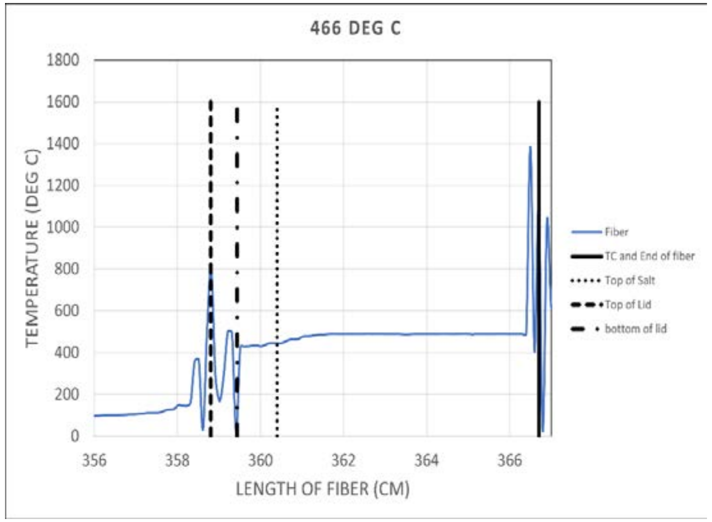
Bottom of Lid: 359.44 cm

Top of Salt: 360.4 cm

Bottom of crucible (inside): 367.2 cm

Glassy carbon rod dipped in molten salt – to demonstrate Depth of salt bath

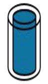




Project accomplishments: reactor simulations

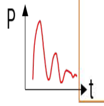
- Completed simulation of reactor transient response under normal conditions and fault scenarios

Neutronics (SERPENT)



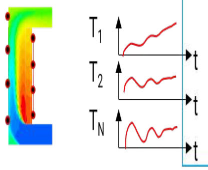
- ✓ Generation of neutronics parameters
- ✓ 0-D/3-D, Steady state
  - ➢ Neutronics: static fuel at constant temperature

Coupled neutronics/T-H (Simplified MSR Kinetics Model)



- ✓ Transient response of state variables (power, salt and structure temperature, reactivity, etc.)
- ✓ Lumped model, transient
  - ➢ Neutronics: effects of precursor transport due to flow T/H: energy balance only, constant flow rate

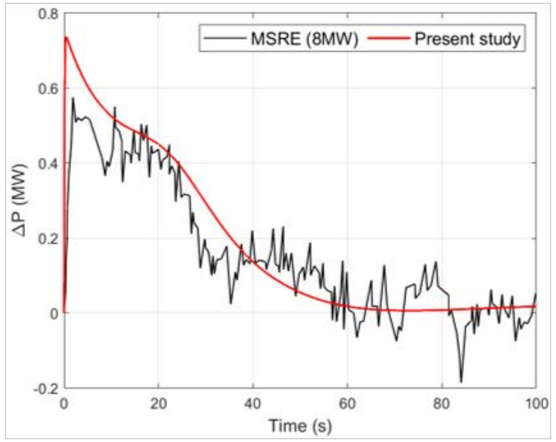
Thermal-Hydraulics (Star-CCM+)



- ✓ Thermal response of MSR in time and space
- ✓ 2-D (or 3-D), transient
  - ➢ Neutronics: power changes imported from simulator
  - ➢ T/H: momentum/energy balance incl. convective and radiative heat transfer of salt

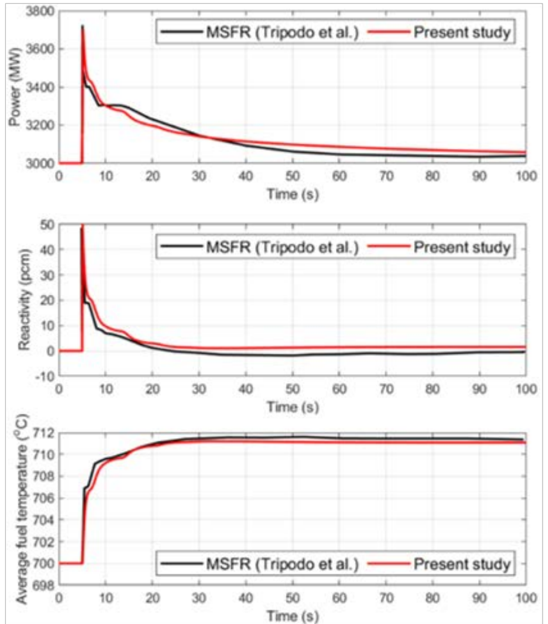
Validation

ORNL MSRE Data

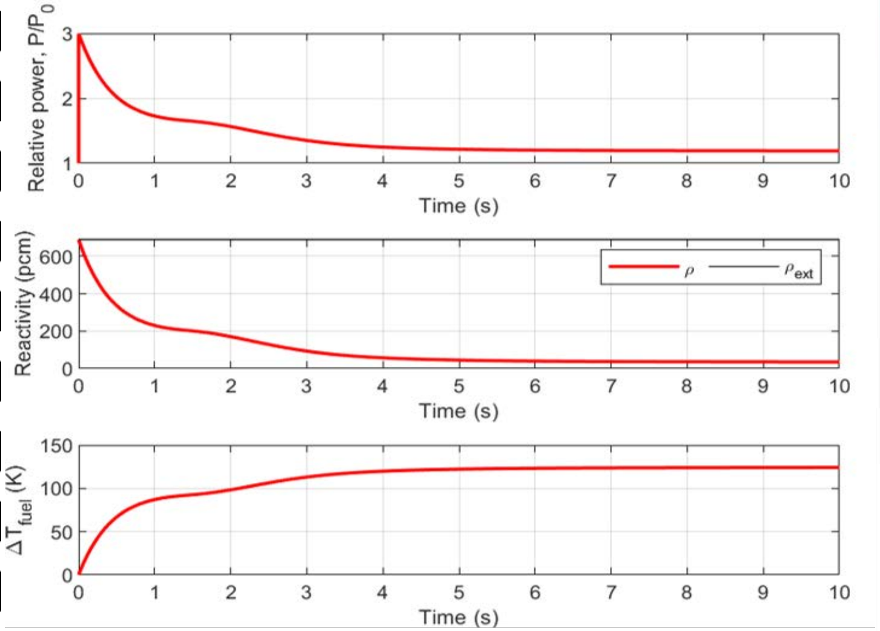


Verification

European MSR Simulator



MCFR Application
(Based on Available Literature on TerraPower MCFR Design)



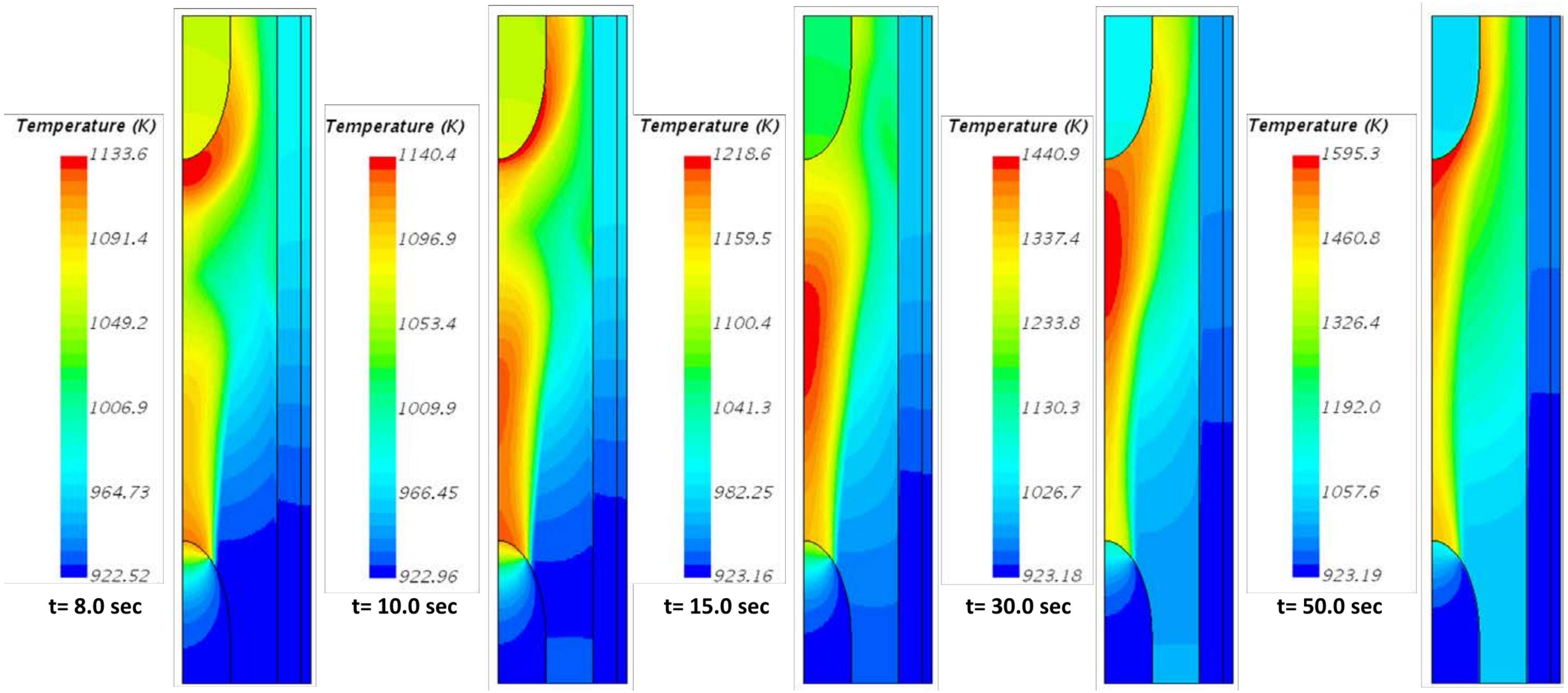
$\Delta\rho = +2\beta$

Transient response of power, reactivity, and fuel salt temperature changes (1)

TEA sim: sampling rate and resolution

Technology-to-Market

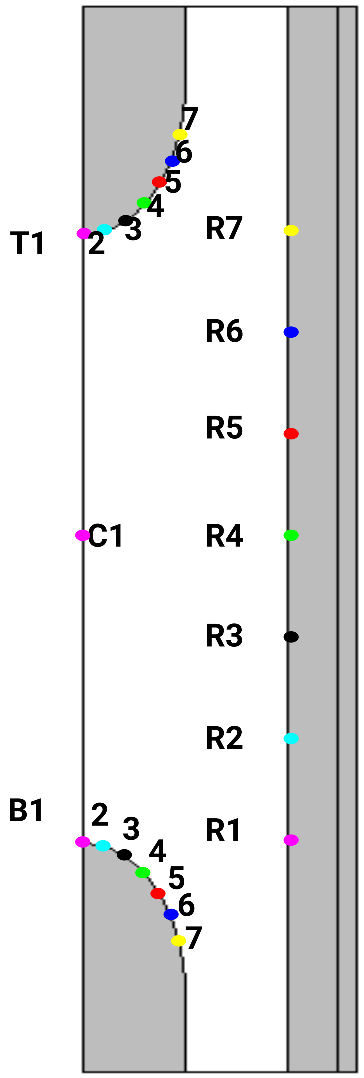
- Demonstrates the Techno-Economic Value of Continuous Temperature Monitoring
  - ✓ Temperature distribution in the salt, reflector and vessel walls experience meaningful gradients and local peaks



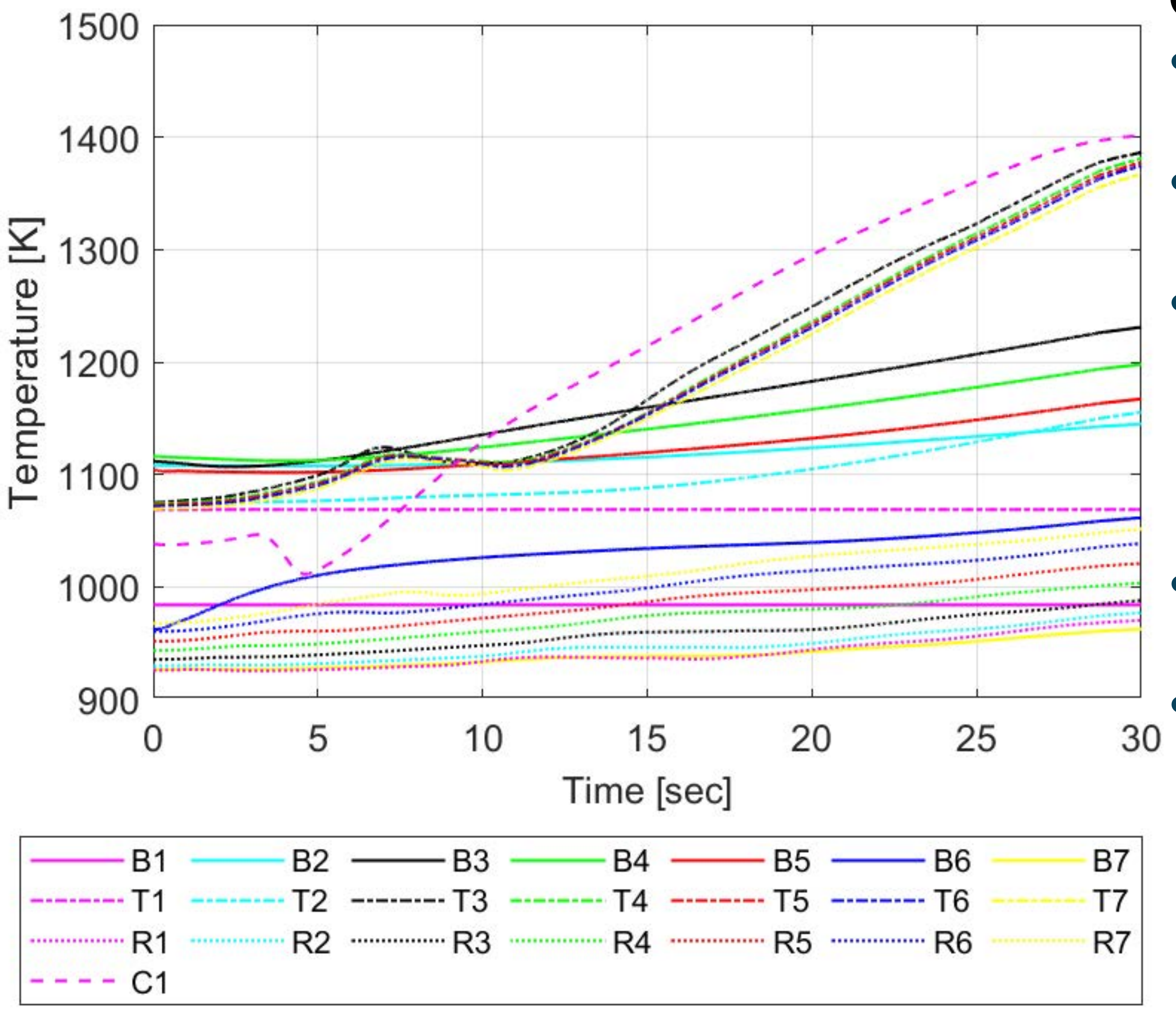
Unprotected LOF (Decrease of fuel salt flow rate to 80 % exponentially with time constant of 5 sec)

CHANGING WHAT'S POSSIBLE

TEA Simulations: sensor placement



Unprotected LOF



Other T2M activities:

- Meetings with Made in Space
- Discussions on Molten Salt CSP applications
- "Dopant segregation in YAG single crystal fibers grown by the laser heated pedestal growth technique" – Journal of Crystal Growth
- Plans: year 2 field tests (INL, MIT research reactor)
- Plans: market the total package – fiber, interrogator, and control software

Single Crystal Distributed Sensing

Feedback

- For new teams:
  - focus on T2m early, this is a SLOW industry
  - Simulations are your friend, because operations do not exist yet
- For ARPA-e
  - Project manager changes went well, but are surprising
  - Good work dealing with COVID-related changes / adjustments